driver behaviour; seat belt use; macro model

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MACRO MODEL OF SEAT BELT USE BY CAR DRIVERS AND PASSENGERS

Summary. The article presents some problems of seat belt use by car drivers and passengers. It looks in particular at seat belt use and effectiveness in selected countries. Next, factors of seat belt use are presented and methodology of model development. A macro model of seat belt use is presented based on data from around fifty countries from different continents.

MAKROSKOPOWY MODEL UŻYWANIA PASÓW BEZPIECZEŃSTWA PRZEZ KIEROWCÓW I PASAŻERÓW

Streszczenie. W przedstawionym artykule przedstawiono poruszono niektóre zagadnienia dotyczące stosowania pasów bezpieczeństwa przez kierowców i pasażerów w pojazdach. W szczególności przedstawione zostały problemy stosowania pasów bezpieczeństwa w wybranych krajach oraz ich skuteczność. Następnie przedstawiono czynniki wpływające na poziom stosowania pasów i metodykę opracowania modelu. Przedstawiono także makroskopowy model używania pasów bezpieczeństwa opracowany na podstawie danych z kilkudziesięciu krajów z różnych kontynentów.

1. INTRODUCTION

Apart from road safety compliant infrastructure, there are other measures such as education, enforcement and vehicle design which help improve road safety. Considered the most effective passive safety protection, seat belts in vehicles are a good example of how car occupants can be protected against the consequences of road accidents [5].

History of seat belt use. Seat belts were first used in aircraft in 1912. It was not until the 1930s that a few US physicians had put in lap belts in their cars and started urging manufacturers to provide seat belts in all new cars. In the 1950s US sports clubs required drivers to wear seat belts during car races [2], [5]. In 1956 Volvo introduced two point seat belts. Ford and Chrysler offer lap belts as an option in some of the models. In 1959 Volvo introduced three point seat belts in front seas as standard equipment. The standards were picked up by Mercedes as well. In 1969 Japan and Australia made seat belt wearing compulsory in the front and rear seats, a regulation followed by many other countries.

In 1964 the majority of US companies introduced lap belts in front seats. This was followed by seat belts made compulsory in school buses, child restraints, automatic seat belts, etc. Not all state authorities, however, had made seat belts wearing compulsory at the same pace. Seat belts have only been compulsory as a primary safety measure across the US for a few years. It is estimated that in the US since 1974 seat belts have saved the lives of 195 thousand people.

In 1965 Europe introduces compulsory front seat belts marking the start of a successive implementation of seat belts for all car occupants. As an example, in the United Kingdom between 1973 and 1986 there were several attempts to make seat belt wearing compulsory. It took 10 years to complete the task. 1983 saw the introduction of a three year trial period of compulsory front seat belts in passenger cars. It was made a law in 1986. Since then around 90% of drivers and passengers have been using seat belts. The efforts were accompanied by a number of advertising campaigns to encourage seat belt wearing such as “Click” and “Elephant”. In 2003 on the 20th anniversary of seat belts in the United Kingdom it was announced that seat belts had helped save 50,000 human lives.

Seat belts in passenger cars were introduced in Poland in 1983 to be worn in front seats in rural areas. The regulation was extended in 1991 making rear seat belts compulsory in built-up areas as well. The decisions were made at the same time as in the United Kingdom, which shows that Poland learned from good examples. The problem, however, is that there were no studies of seat belt wearing. As a result, we cannot estimate the effects.

In 1996 the European Commission approved amendments to three directives on seat belts, anchorages and the number of seats in mini buses, medium sized buses and large buses. Seat belts were also made compulsory in micro buses [5].

Seat belt use. Fig. 1 shows seat belt data from selected countries in the world in 2007 (based on WHO data) [16]. After analysis we can see that the average rate of seat belt use is 65% for front seat occupants and 41% for rear seat occupants. The chart also shows strong variations in seat belt use ranging from 0% in Cambodia, Togo and many other developing countries, through 10% in Bangladesh, 78% Poland to 97% in Sweden, Australia, France and Japan.

Previous analyses [6 - 9] showed that seat belt use depends on legislative action reinforced with public campaigns and advertising and intensified enforcement. This can be illustrated with a chart of how seat belt use changed in several selected countries. The impact of legislation and enforcement is particularly strong in Japan, Poland and Switzerland (Fig. 2).

Poland first made seat belts compulsory by law in 1983. Drivers and front seat passengers were required to wear seat belts in rural areas. As a result, in 1990 about 25% of car occupants in Poland wore seat belts which was anything but impressive because at the same time front seat car occupants in the United Kingdom (seat belts were made a law in 1983) and Sweden wore seat belts at rates of about 90% and 70% in Switzerland.

When seat belts were made compulsory for all car occupants (including rear seats if fitted with seat belts) in 1991, seat belt use increased significantly to reach 76% in 1996. Since then, seat belt use by front seat car occupants in regional capitals had been similar (slightly more than 70%) but levelled off subsequently. It was not until the end of 2005, following a media campaign and intensified enforcement that the rates started to climb up. Sadly, in 2008 systematic monitoring of seat belt use in Poland was terminated.

Analyses have shown that between 1990 and 2009 in Poland 120 thousand people were killed in road accidents, including 65 thousand drivers and passengers of cars and buses. Seat belts have saved 10.5 thousand people but if 95% of car occupants during that period had worn seat belts, the total number of people who could have been saved from fatal road accidents would be 36 thousand drivers and passengers. This is why one of fifteen priorities in the National Road Safety Programme GAMBIT 2005 for the years 2005 – 2007 – 2013 [10] was to increase the rate of seat belt use from 72% in 2003 to 95% in 2013 (for front seat car occupants). Sadly, despite a significant effort we are still off target. This suggests that Poland needs to take determined steps to improve road traffic education and enforcement to increase its seat belt wearing rates and reach levels similar to those of Europe’s leading countries. There is a lack of methods and models for estimating the effectiveness of national efforts, which are significant for the development of Poland’s National Road Safety Programme until 2020.

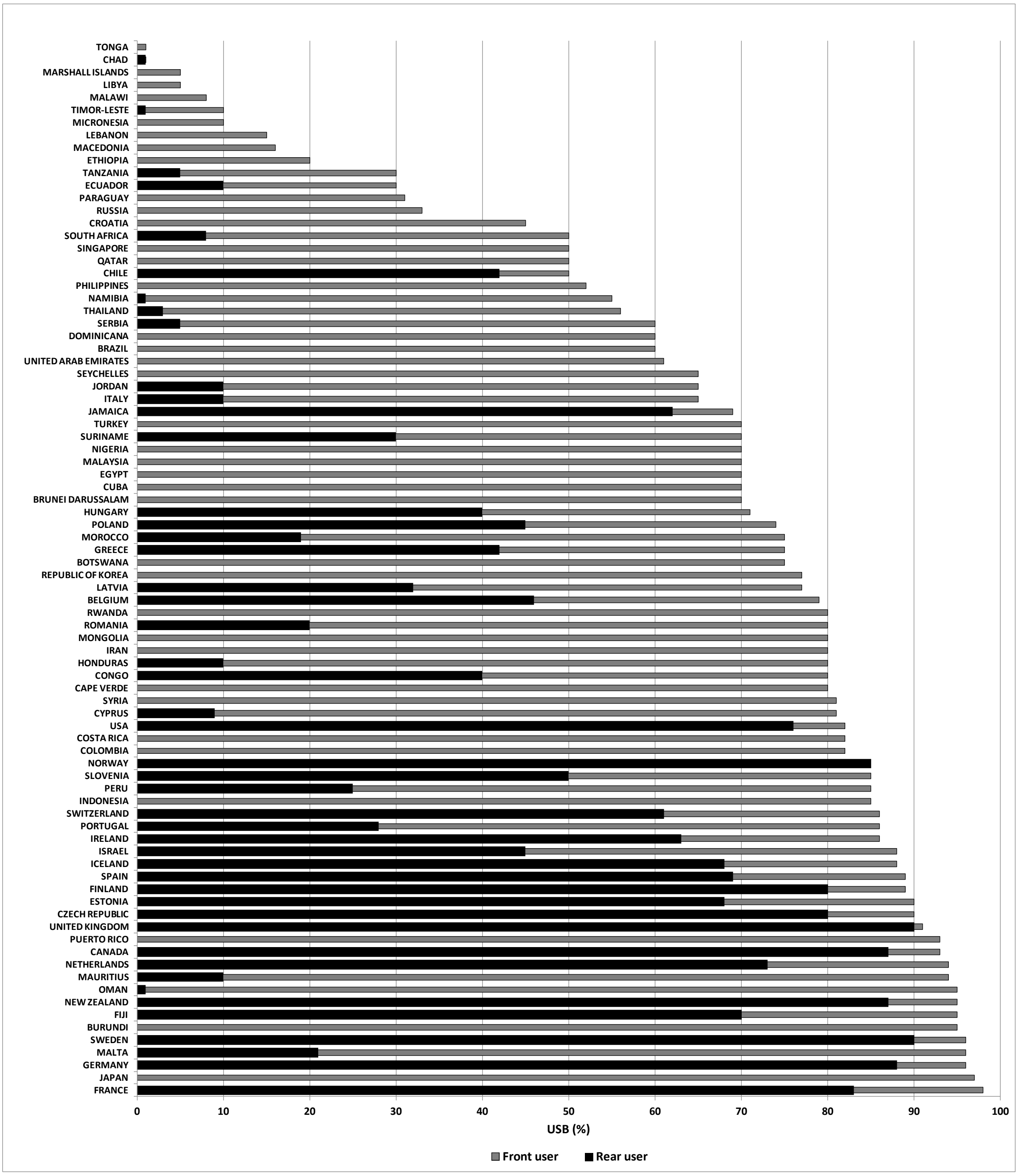

Fig. 1. Distribution of seat belt use by car occupants in selected countries worldwide in 2007, based on WHO data [16]

Rys. 1. Rozkład stosowania pasów bezpieczeństwa przez uczestników ruchu w pojazdach w wybranych krajach świata w roku 2007, oprac. własne na podstawie danych WHO [16]

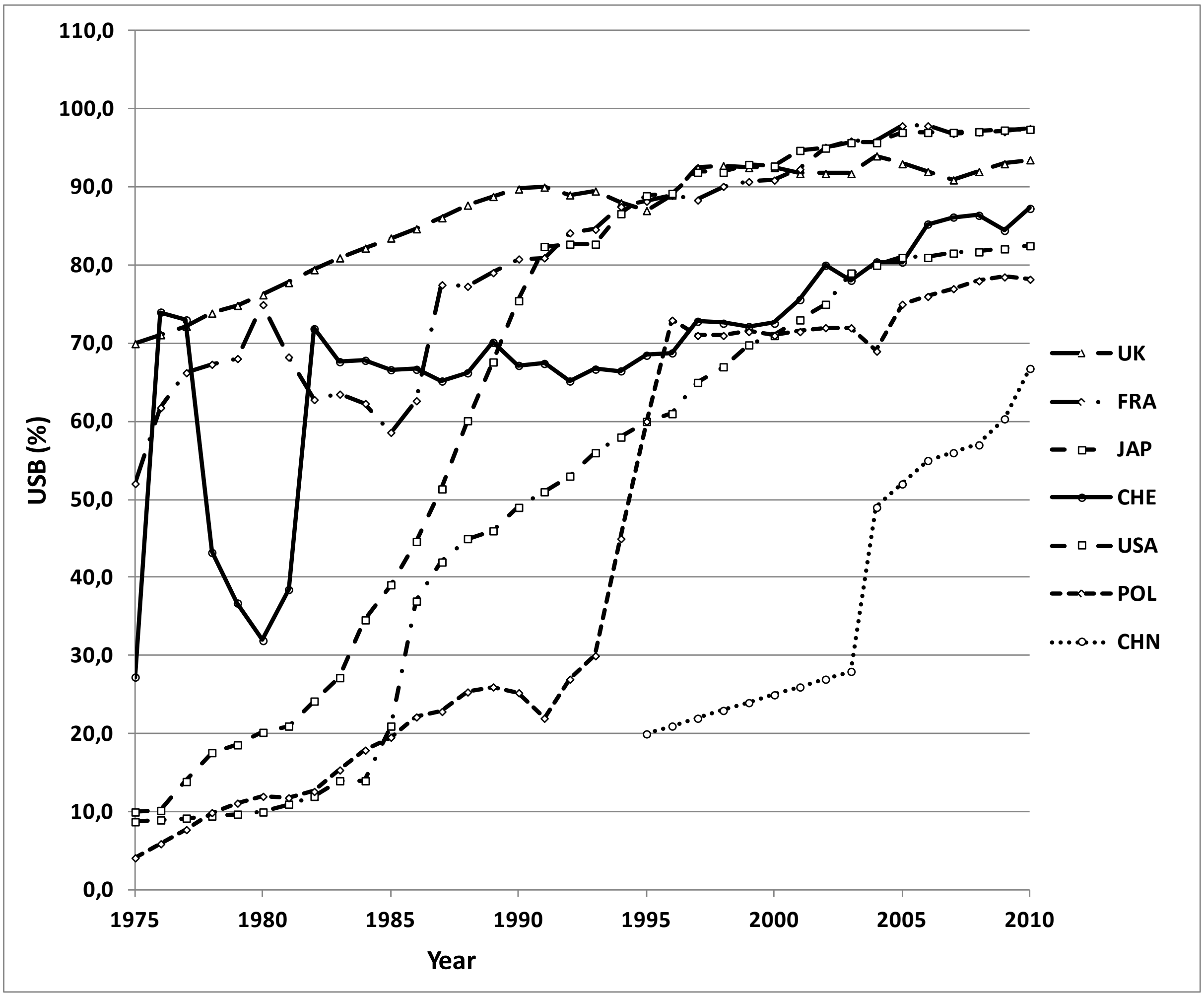

Fig. 2. Changes in car occupant seat belt rates in selected countries
Rys. 2. Zmiany wskaźnika udziału uczestników ruchu w pojazdach stosujących pasy bezpieczeństwa w wybranych krajach

2. THEORY

Role of seatbelts. Seat belts counteract the first and second impact. The first impact is when a passenger or driver is ejected from the vehicle and hits elements outside the vehicle (a tree, another vehicle, roadway), the second impact is when a car occupant hits the interior of the vehicle [2]. Seat belts are designed to secure the driver and passenger in the seat during emergency braking or when the car hits an obstacle to neutralise the inertia causing the human body to move towards the windshield and the obstacles in front of the windshield and outside it. When a vehicle hits a stationary obstacle it decelerates over a distance equal to the deformation of the structure, which is tens of centimetres. Given these significant delays of movement, the human body increases its apparent weight by fifty times or so, but the consequences of the body hitting an obstacle are anything but apparent. Seat belts must prevent the consequences of the impact.

Models of driver and passenger behaviour towards road risks. The behaviour of road users is explained in some behavioural theories. The basic feature of all behavioural theories is how people assess risk and accept it, which is a very important determining factor of accidents. Behavioural theories distinguish two approaches: individual and societal. The individual approach applies to how individuals behave (road users, employees, residents), while the societal approach applies to social groups (those involved in a crash, local communities, the population of a country). Of the many behavioural theories the following have been selected: homeostasis of risk, planned behaviour and injury prevention [11].

Theory of risk homeostasis. Gerald Wilde, who created the theory, found that:

- Every road user has his or her own fixed level of acceptable risk and when a situation is safer or less safe compared to that fixed level, there will be a corresponding rise or fall in risk when driving,
- Every community only has as many accidents as it wants to have and the only way to reduce that number is to change the level of risk (desired safety level) [17, 18].

Theory of Planned Behaviour shows that a change of behaviour depends on the intentions, which are controlled by attitudes, subjective norms and perceived behaviour control [1]. Studies have shown that the theory could be used to explain why car occupants choose to wear seat belts [13].

Behavioural theory of injury prevention. This theory builds on environmental theories and explains the effects of health oriented behaviour of individuals and society on casualty. According to the theory the number of victims or the likelihood of becoming one depends on health promotion (education, public campaigns, programmes, policy, legal regulations, organisational changes), human factors (local level, social level) and the behaviour of society and effects of the surrounding environment.

As one of i*ndividual health models*, this model includes preventive action, which relies on people's belief in the ability to change their well-being, reduce severity of illness and increase the effectiveness of efforts if they accept the proposed preventive methods [12]. This model can be applied to explain why car occupants use seat belts. According to the model there are two main groups of factors that make the driver or passenger fasten their seat belts: the reasons (suggestions) as a result of social pressures, health education, information campaigns and attitudes influenced by perceived risks (proneness to injury, accident consequences), general health motivation and value of behaviour (perceived benefits, perceived barriers and inconvenience) [13].

Societal health models such as society organisation or mobilisation provide models which shows the involvement of the public in defining health problems and applying effective measures of prevention such as public health programmes, local programmes, including road safety programmes. The process involve a change in the structure of society and forms of management, pressures on authorities, support for research, etc. [4].

The theory of injury prevention may change how decision-makers take decisions to change the law and implement new engineering solutions to protect the public from risk of injury or death. We can distinguish two groups of health changes people can make: individual and societal.

Factors affecting seat belt use. Studies of literature shows that seat belt wearing by car occupants is determined by a number of factors. These can be grouped into:

- personal factors: individual (age, road user gender, psychological choices, genetic factors, factors of individual risk), societal (social connections and relations, living standards, presence of other people in the vehicles, other people's behaviour),
- surrounding factors: local (the vehicle and its equipment, road, urban, rural area, weather), external (institutions, law, social and economic policy, health policy education, level of social and economic development).

Based on the above, the following are the main orientations of interventions to increase seat belt use by car occupants. They are: effective law, education and public relations (public campaigns), road traffic enforcement (prevention and repression) and vehicle design technology (cars equipped with seat belts).

3. METHODS

Measures can be implemented at different levels: strategic (national), regional and individual (road user). This paper, however, focuses on strategic level interventions. A macro model is proposed to understand seat belt use by car occupants. No strategic level seat belt use models have been found in literature.
The seat belt measure is the USB described in the formula below (1).

$$USB = \frac{OSB}{O} \cdot 100 \tag{1}$$

where: *USB* – share of car occupants wearing seat belts (%) , *OSB* – number of car occupants wearing seat belts (occupants/year), *O* – number of cars overall (occupants/year).

A number of available databases were used, including Eurostat, FAO, IRF, IRTAD, OECD, TI, UN, WB, WHO and many other sources, to collect empirical fatality data and a number of other parameters characteristic of selected countries over the years. They are geographic, demographic, economic, social, motorisation, road and transport variables. The number of countries was narrowed down to those, which have seat belt use data available over extended periods. This was the basis for preparing data for 61 countries over a period of 1965 – 2010 representing a set of more than 1800 country years.

Building on previous analyses conducted by the author, several most significant strategic factors were identified which have an effect of seat belt rates [3], [8], [9], [11]. In order to select the key independent variables an analysis was conducted looking at the relations between independent variables (X) and the USB seat belt rate as a dependent variable. The variables relation was studied using Pearson product-moment correlation coefficient R, which is a measure of the strength of linear dependence of two measurable features. Neural networks were also used to determine the strength of the relation between non-linear variables. Detailed analyses on a group of 30 factors have helped to identify the key factors: level of social and economic development (measured with the gross national product per capita GDPPC), the degree of state organisation (measured with the perceived corruption index CPI), education index EDI, motorisation rate MRG and types of vehicles PMV, degree of urbanisation (measured with the percentage of urban population PUP), type of development (measured with the percentage of arable land PAL), interventions in place (effectiveness of seat belt use LOI) and legal requirements (compulsory use of seat belts).

4. RESULTS

The author used the data collected to develop a model for estimating seat belt use by car occupants, the USB. Key to model development is the shape of mathematical function for describing the relation between dependent and independent variables. The concept of the USB model was based on the concept of self-regulating systems with saturation, i.e. a sigma type model [11]. Three types of functions were analysed each describing the relation between USB and independent variables (logistic - hyperbolic, logistic and Gompertz).

$$USB = \frac{USB_{max}}{1 + \beta_0 \cdot \prod_{i=1}^{n} X_i^{\beta_i}} \tag{2}$$

The growth cut-off line is interesting in the models. In the case of the USB rate the value is set at USB_{max}, at which point all car occupants use seat belts and the USB_{max} = 100 %.

The second important element is to select the parameter of scale of the independent variable. Previous work by the author [hab.] shows that changes in road safety measures and in a number of independent variables typical for levels of motorisation, condition of the road network and road safety depend on the country's level of socio-economic development. This is most often described with the gross national product per capita GDPPC. Figure 3 shows how the USB rate changes vs. the degree of social and economic development $GDPPC_i$ in selected countries.

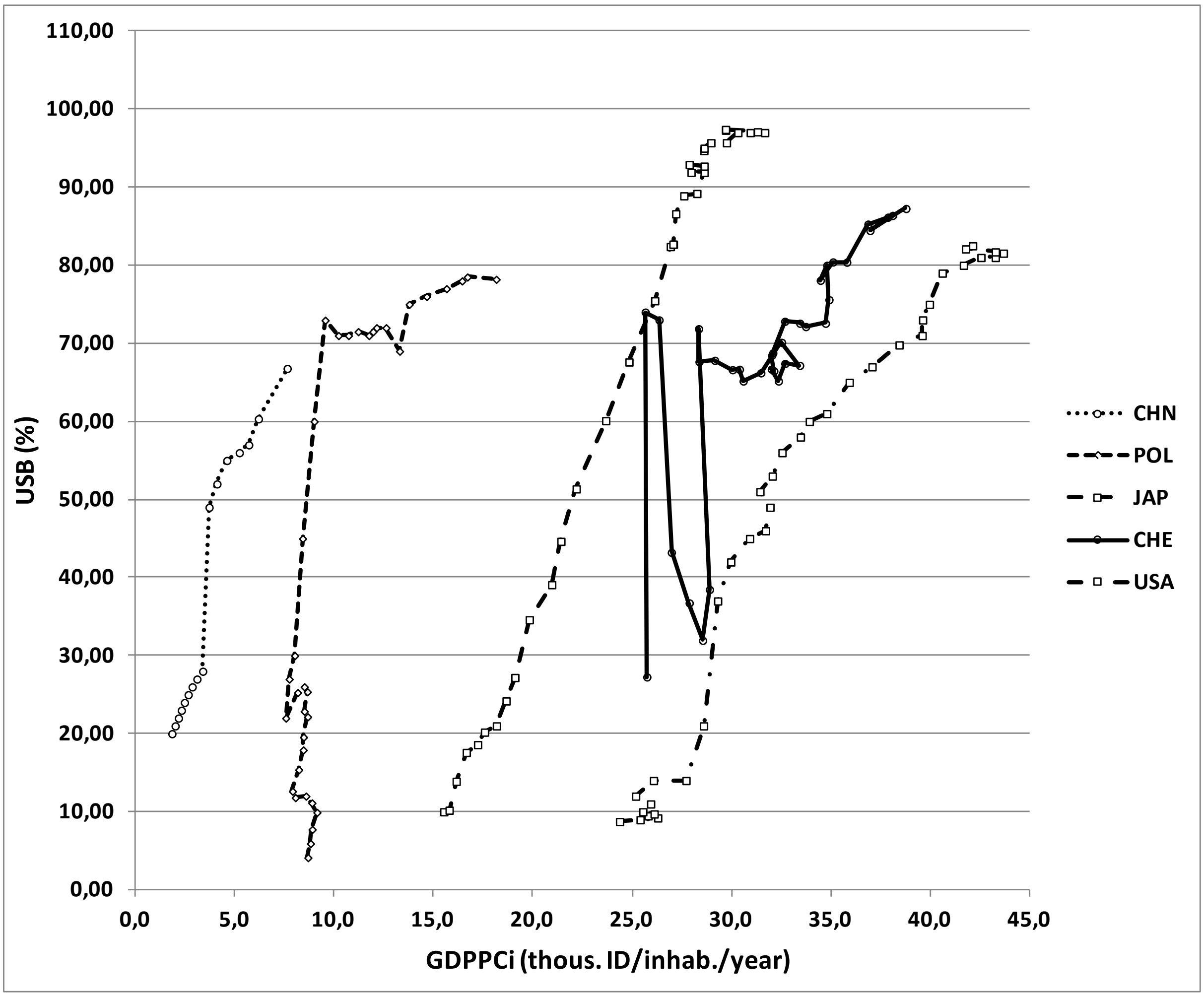

Fig. 3. Changing USB depending on the degree of social and economic development $GDPPC_i$ in selected countries

Rys. 3. Wykresy zmian wskaźnika USB od stopnia rozwoju społeczno-gospodarczego $GDPPC_i$ w wybranych krajach

Seat belts in vehicles came into a wider use in the 1960s to become more widespread in the 1980s. Within this period the individual countries reached different levels of socio-economic development (as illustrated in Figures 3 and 4). Seat belts were made mandatory:

- in developing countries for $GDPPC_i$ = 1 – 8 thousand ID inhabitants/year,
- in developed countries for $GDPPC_i$ = 10 – 18 thousand ID/ inhabitants /year,
- in rich countries for $GDPPC_i$ > 20 thousand ID/ inhabitants /year.

Considering the above, a normalised $GDPPC_n$ was adopted as a parameter of scale of an independent variable. The indicator was then calculated using the relation (3) as the difference between the country's current $GDPPC_i$ and its value $GDPPC_o$ when seat belts were made mandatory in that country.

$$GDPPC_n = GDPPC_i - GDPPC_o \tag{3}$$

The following conditions were used for estimating seat belt use:

if:

$$GDPPC_i \leq GDPPC_o \quad then \quad USB = 0 \tag{4}$$

if, however:

$$GDPPC_i > GDPPC_o \quad then \quad USB\ adopts\ values\ calculated\ using\ the\ relations\ (2) \tag{5}$$

The distribution of $GDPPC_o$ shown in Fig. 4 is within the range from 0.8 to 45 thousand ID/1 inhab./year. As an example, in the case of China $GDPPC_o$ = 1.0; in the case of Poland 5.5 and in the case of the US 25.5 thousand ID/1 inhab./year.

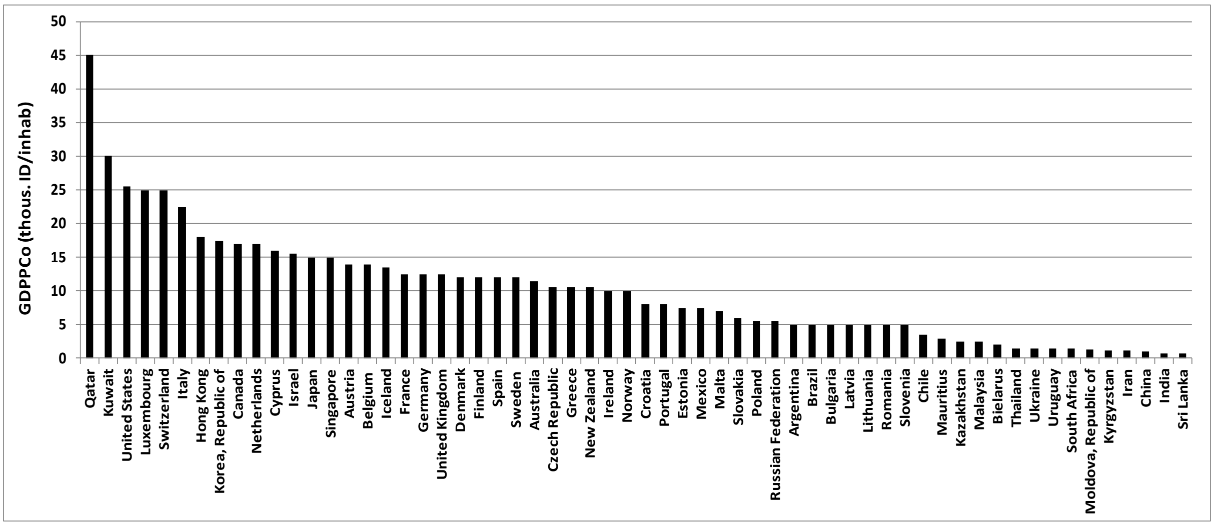

Fig. 4. Distribution of $GDPPC_o$ (gross national product per capita – in the year when seat belts became compulsory) in selected countries

Rys. 4. Rozkład $GDPPC_o$ (jednostkowy produkt narodowy – w roku w którym pasy bezpieczeństwa zastosowano obligatoryjnie) w wybranych krajach

Model parameters were identified using the STATISTICA software [14]. The result was a relatively good match between the models and real data (coefficient of determination $R^2 = 0.5 – 0.73$). It was, however, the logistic-hyperbolic model that provided the best match versus real data, presented in its general form in equation (6).

$$USB = \frac{100}{1 + \beta_0 \cdot GDPPC_n^{\beta_1} \cdot MRG^{\beta_2} \cdot \mathrm{PMV}^{\beta_3} \cdot \mathrm{PUP}^{\beta_4} \cdot \mathrm{PAL}^{\beta_5} \cdot \mathrm{CPI}^{\beta_6} \cdot \mathrm{EDI}^{\beta_7}} \cdot CMF_{(USB)} \tag{6}$$

where:

$GDPPC_i$ – gross national product per capita (thousands ID/inhabitants/year), (PPP, constant 2005, international \$), $GDPPC_n$ – gross national product per capita – normalized (thousands ID/inhabitants/year), (PPP, constant 2005, international \$), $DPPC_o$ – gross national product per capita – in the year when seat belts became compulsory (thousands ID/inhabitants/year), (PPP, constant 2005, international \$), *MRG* - motorisation rate, general (vehicles/1 thou. inhabitants/year), *PMV* - percentage of motor vehicles (except two and three wheelers), *PUP* - percentage of urban population (%), *PAL* - percentage of arable land (%), *CPI* – corruption perception index, *EDI* – education index, $CMF_{(USB)}$ – country modification factor, $\beta_o, \beta_1, \cdots \beta_n$ – equation coefficients.

5. DISCUSSION OF RESULTS

The model shows that the essential macro level factors (country strategic level) influencing the rate of seat belt use by car occupants include the levels of country's socio-economic development, education, state institutions, land use, urbanisation and the level and structure of motorisation.

Level of social and economic development of a country can be measured with a number of figures. For the purposes of this paper, development is measured with the gross national product per capita GDPPC, measured in international dollars (ID) per inhabitant of the analysed country (PPP, constant 2005). In Poland this indicator in 2010 was 18.3 thousand ID/inhabitant. However, as mentioned before, the time of the intervention is critical (i.e. introduction of seat belts). This is why a corrected value of $GDPPC_{kor}$ is used (based on formula 3). Fig. 5 shows a chart of the effects of selected factors (corrected level of socio-economic development $GDPPC_{kor}$ and education level EDI) on seat belt use. The charts show that in the initial period when seat belts are made mandatory the USB is growing very quickly. Within a short period, i.e. when $GDPPC_i$ grows by 10 thousand ID/inhab./year, depending on the level of education and other factors, many countries reached similar seat belt rates of 50 – 70 %, for average elasticity of 0.96, followed by inflection of the function and a slow approach towards the asymptote represented by USB_{max} = 100 %, with average elasticity of 0.31. This factor will also have a positive effect on seat belt use in the years to come.

Level of education, measured here with the education development level EDI *(Education index)*, is calculated based on the share of adults who can read and write and the number of primary and secondary school students. Data are available in UN reports [UN-2005]. Poland has a well developed system of education because in 2010 the EDI = 0.812. As we can see in the charts in Fig. 5, the higher the level of education, the more people use seat belts. As a result, as the education rate EDI approaches 1.0 over the years to come, the USB will grow at average elasticity of 0.47.

Level of institutional development of a country as described here is represented by the CPI indicator *(Corruption Perception Index)* which shows corruption as perceived by the world's business community and economists and experts living in that country. This is a study conducted by Transparency International (TI) where each country is assessed on a scale from 10 (most transparent) to 0 (most corrupt). In 2010 in Poland the indicator was CPI = 5.3. Sadly, at the time Poland was number 20 in the EU and 41 in the world. It is also referred to as the indicator of "health" of the economy and one describing the degree of governance in the country. The underlying data are available in selected international databases. The results of the analysis show that corruption has a very significant effect on seat belt use; the lower the corruption, the higher the seat belt use. As a result, as the CPI increases towards 10.0 (meaning perceived corruption does not exist) over the years to come, the USB will grow at average elasticity of 0.20.

Land use, the measure applied here is the share of arable land PAL, i.e. the relation between the country's arable land and overall area of the country. In Poland the rate is 40.3%. The model was analysed for this relation and it was established that as the share of arable land increases, so does seat belt use and average elasticity is 0.04. This factor, however, is not significant for the USB because it changes very little.

Level of urbanisation, the measure applied here is the share of urban population PUP which is the relation between the country's population and area of the country defined as the number of people per 1 km^2. In Poland the rate in 2010 was PUP = 62.8%. The model was analysed with this rate and it was established that as urban populations increase, seat belt use decreases, with average elasticity of -0.12. This factor, however, is not significant for the USB.

Level of motorisation, the measure applied here is general motorisation rate MRG which is the relation between the number of vehicles and the country's population. Vehicle data are published by statistical offices of many countries and worldwide statistical databases. The rate in Poland in 2010 was more than 610 vehicles/1000 population. The data were analysed and suggest that for the same rate of socio-economic development, seat belt use increases when motorisation rate increases with average elasticity of 0.04. Considering this, the factor will not be significant for changes in the USB.

Structure of motorisation, the measure applied here is the share of motor vehicles versus all vehicles PMV. In Poland in 2010 the rate was PMV = 62.8 %. The model was analysed for this rate and it was established that as the share of motor vehicle increases, seat belt use decreases with average elasticity of -0.11. Because the PMV changes very little, this factor will be of minor significance for the USB.

Other factors. Apart from general factors, each country has its local factors such as the level of traffic enforcement, information campaigns and other interventions designed to increase seat belt wearing. The model represents these factors using the indicator $CMF_{(USB)},$ calculated as the degree of the match between the model and national data for the period 2008 – 2010. The average value of this indicator is 1.07 with standard deviation at 0.2. In the case of Poland the figure is $CMF_{(USB)} = 1.03$. The interventions listed above may have an effect on seat belt use in the years to come.

Fig. 6 shows how the USB changes in response to the interventions. The results suggest that the country's socio-economic growth will be accompanied by a growing seat belt rate. Unfortunately, the increase (alternative A) may be far from the expectations and a more intensified package of interventions is needed to speed up the process of improving seat belt rates (alternative B).

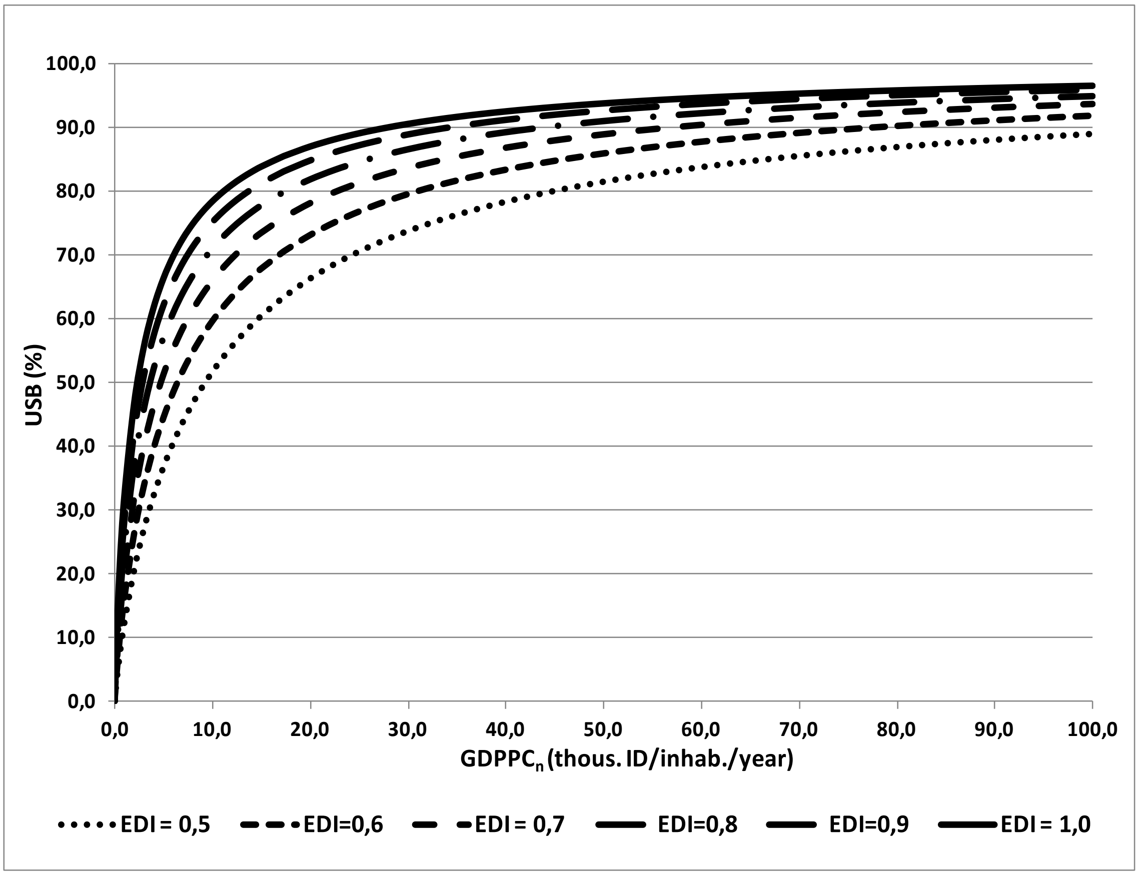

Fig. 5. Chart of the relation between USB and corrected level of socio-economic development $GDPPC_{kor}$ and education index EDI

Rys. 5. Wykres zależności wskaźnika USB od skorygowanego poziomu rozwoju społeczno-gospodarczego $GDPPC_{kor}$ i wskaźnika rozwoju edukacji EDI

Based on the model (described with formula 6) and forecasts of independent variables developed by the author [11], a forecast was developed of how Poland's seat belt use by car occupants would change until 2050. Two alternative interventions were adopted:

– alternative A based on the country's natural socio-economic development,
– alternative B including additional interventions such as intensified information campaigns and intensified traffic enforcement (to be undertaken in the coming years 2013 – 2020).

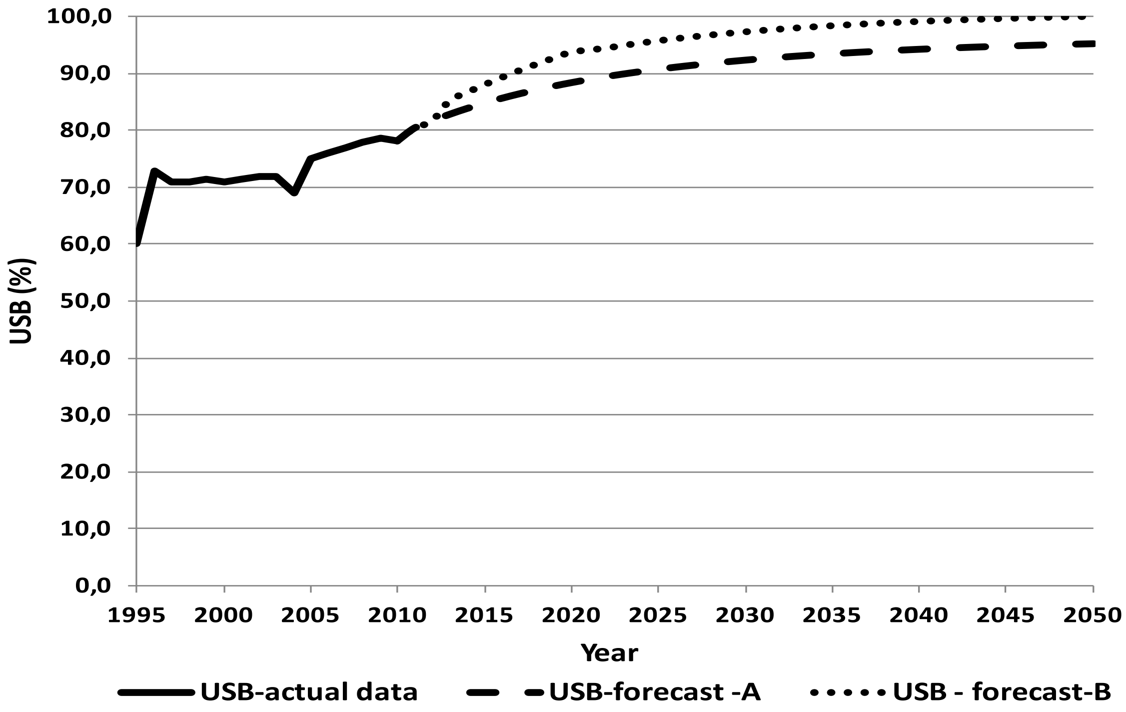

Fig. 6. Relation between the existing and projected USB factor and interventions to be conducted until 2050 in Poland

Rys. 6. Wykres zależności wskaźnika istniejącego i prognozowanego USB od wariantu prowadzenia interwencji do roku 2050 w Polsce

6. CONCLUSIONS

Analyses of the results suggest that in the period 2008 – 2010 in Poland seat belt use by car occupants reached 78%. The degree of seat belt use estimated with the model is only slightly different (- 3.0%) from the results based on measurements. This shows that the model can be used for forecasting seat belt wearing rates, taking account of the correction coefficient $CMF_{(USB)}$. The main factors of change of seat belt use by car occupants USB include socio-economic growth, higher level of education, lower rate of corruption, intensified interventions to promote and enforce seat belt wearing, including the mandatory use of seat belts and a system for checking seat belt wearing by car occupants.

The model was used to develop a forecast of Poland's seat belt use rate until 2050. It shows that as the country increases its rate of socio-economic development, more and more car occupants will wear seat belts. Unfortunately, the pace of that increase may not be fast enough and additional interventions (campaigns, road traffic enforcement) are required to accelerate the growth of seat belt use by car occupants.

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